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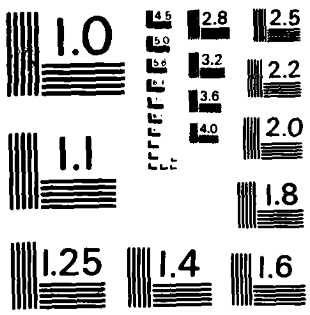

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GROUNDWATER CONTAMINATION RESPONSE GUIDE

Volume I: Methodology

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The technical report documents an overview of groundwater hydrology and a current technology review of equipment, methods, and techniques used in groundwater field investigations. Numerous topics applicable to the planning, scheduling, data collection, and integration steps essential in a comprehensive field program are addressed. The report, targeted for installation engineers and managers responsible for evaluation of or response to suspected instances of groundwater contamination, consists of two volumes. Volume I: Methodology. An assessment methodology, for investigating and evaluating (Continued on reverse)

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known or suspected instances of contaminated groundwater, is described. The methodology provides a starting point from which information gathering and data collection actions can be initiated. While response actions remain site-dependent, a general and logical approach to field activities is presented. An introductory summary of field investigative methods and analytical techniques, with data integration steps, appraises installation engineers of the complexities of field programs. Volume II: Desk Reference. A comprehensive survey of technical works resulted in this compilation of groundwater fundamentals and field investigation activities. Topical coverage ranges from hydrology basics to state-of-the-art equipment and field methods. Sufficient material is presented to acquaint the reader with basic concepts and fundamentals of groundwater and water quality issues. Numerous illustrations highlight these items. An applications oriented review of field methods identifies equipment types and limitations. The essentials of geophysics, drilling methods, well construction and sampling are addressed, with emphasis on integrating information in an iterative process to devise a cost-effective program. A review of contaminant transport in groundwater identifies significant parameters and physical systems of concern. Finally, a summary of groundwater treatment methods provides an options list for potential use. The report concludes with an agency address directory for water quality information and some representative cost schedules for field activities.

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PREFACE

This report was prepared by Arthur D. Little, Inc., Acorn Park, Cambridge. Massachusetts, under contract F33615-80-D-4002 for the Engineering and Services Laboratory, Air Force Engineering and Services Center (AFESC), Tyndall Air Force Base, Florida.

This report documents work performed between June and September 1982. The AFESC/RDVW project officer was Captain Glen E. Tapio.

Several volumes of technical material were critically reviewed and compiled during preparation of this report. Expert summaries were provided by the following individuals:

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This report provides a review of equipment, methods, and technologies used in groundwater quality investigations. While serving as a current technology reference, the information will also provide input to developmental efforts leading to more efficient, durable, and cost-effective monitoring and remedial action technologies.

This report is not to be used for promotional or advertising purposes. Citation of trade names does not constitute an offical endorsement or approval for use of such commercial products. The views expressed herein are those of the authors and do not necessarily reflect the official view of the publishing agency, the United States Air Force or the Department of Defense.

This report has been reviewed by the Public Affairs Office (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS it will be available to the general public, including foreign nationals.

This technical report has been reviewed and is approved for publication.

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SECTION I

INTRODUCTION

Since the mid-seventies, the emphasis on understanding the causes and effects of groundwater contamination by organic chemicals has increased because a few Air Force facilities have encountered significant problems with the presence of organic contaminants under their property. During investigation and cleanup of these known incidents, it became obvious that there was no organized procedure to guide Air Force personnel in determining the location, extent, and level of groundwater contamination, or to select the most appropriate containment or treatment technology. Because Federal legislation related to contamination of groundwater resources affects the Air Force, a methodology to assess and control groundwater pollution by organic chemicals became expedient.

The general problem with protection of groundwater resources is to identify the areas and mechanisms by which contaminants enter the groundwater system, to develop reliable methods for predicting contaminant transport, to select an appropriate contaminant/treatment technology, and to ensure compliance with federal and state legislation.

For Air Force personnel, this requires:

- identification and analysis of available information to estimate the extent, nature, direction, and rate of movement of the contaminant;

- development of a field investigation program to quantify the rate and direction of contaminant movement, as well as the extent of the contaminated zone;

- selection of method(s) for containing the spread of contaminants or treating contaminated groundwater; and

- response to the appropriate federal and state agencies.

To effectively respond to groundwater contamination incidents, the Air Force is developing the capability to rapidly identify organic contaminants in groundwater, to determine pollutant pathways, and to determine the fate of organic constituents in groundwater. The results of this effort will be included in the Spill Prevention and Response Plan for each Air Force installation.

Until such time as the Spill Prevention and Response Plan can be updated, an interim solution is needed. A user-oriented field manual, based on a literature review and describing the current best practicable

methodology for Air Force field personnel to respond to incidents of groundwater contamination by organic chemicals, is proposed.

This Methodology and the companion Desk Reference are designed to help base level engineering personnel to address groundwater pollution problems in a logical manner. This will address such specific issues as:

- the initial response to identified contamination incidents;
- developing a strategy for determining the origin of organic contaminants;
- determining the rate and direction of movement of the pollutants and extent of the contaminated zone;
- identifying possible strategies for control, containment, and cleanup of groundwater contamination.

These volumes do not provide specific solutions for groundwater contamination problems. The data necessary to design the response for a particular contamination incident must be developed from site-specific soil and groundwater investigations. They do, however, describe an overall approach which can be followed to ensure a logical, scientifically based response to a groundwater pollution incident.

The Methodology is a summary document which describes the logical flow of action to be taken in responding to a contamination incident. The Desk Reference is based on a thorough review of the scientific and technical literature related to groundwater contamination and summarizes the state of the art of the various techniques used to identify, quantify, and respond to groundwater pollution incidents.

SECTION II

IDENTIFYING AND ASSESSING THE CONTAMINATION PROBLEM

Initial identification of groundwater contamination is generally unexpected; that is, there usually is no advance warning that a well or spring which has previously had good quality water is going to show evidence of contamination. The complex flow paths which can exist in groundwater systems, the wide variety of contamination sources, and the fact that groundwater flow is not directly observable all contribute to this "surprise factor." When initially informed of a potential groundwater contamination incident, the questions of most immediate concern are usually:

- What is the nature of the contamination?
- What is the source of the contaminant?
- How extensive is the contamination? and
- What is an appropriate remedial response?

1. INITIAL ASSESSMENT

The initial indication of a contamination problem may be water with an unusual taste, odor, or physical appearance, an indication of vegetative or wildlife stress, or it may be noted during routine water quality testing. The initial indication may provide some information regarding the nature of the contaminant, but it will not usually provide information regarding the source, extent, or severity of the problem. These concerns need to be addressed by a problem-specific investigation and analysis program. Table 1 lists the major information categories and specific data elements that usually need to be evaluated during the investigation and analysis program. All of the data elements in Table 1 may not be required for every problem, but they should be considered during the initial problem assessment and definition.

The physical framework includes all the geologic and topographic information which describes the environment through which groundwater and, hence, the contaminant flows. This includes the thickness and areal extent of various geologic units, as well as maps of the spatial variability of water transmitting and storage properties. The hydrologic system is defined by those properties which control water movement through the physical framework. These data include water level information, identification of natural and human-induced recharge and discharge locations, the hydraulic connection between groundwater and surface water, spatial variability of water quality, and other factors which define boundary conditions to the flow system. Site information includes a description of present and past site uses which may provide information regarding the nature and source of contamination, identification of existing monitoring points which may be used in the problem investigation, and construction information, such as the location of buried utilities, which is important for safety reasons, as

TABLE 1. PRINCIPAL DATA REQUIREMENTS FOR GROUNDWATER CONTAMINATION ASSESSMENT

Physical Framework	Hydrogeologic maps showing extent and boundaries of all geologic units
	Topographic maps showing surface water bodies and landforms (including springs and seeps)
	Water table, potentiometric, bedrock configuration, and saturated thickness maps
	Maps showing variations in water-transmitting properties
	Maps showing variations in storage coefficient
Hydrologic System	Water levels and water level changes (maps and hydrographs)
	Depth-to-water map (for evapotranspiration estimates, selection of sampling method)
	Type and extent of recharge areas (irrigated areas, recharge basins, recharge wells, etc.)
	Groundwater inflow and outflow
	Groundwater pumpage (temporal and spatial distribution)
	Climatologic information
	Surface water diversions

TABLE 1. (CONCLUDED)

	Stream flow quality (temporal and spatial distribution)
	Temporal and spatial distribution of groundwater quality
	Relation of surface water bodies (hydraulic connection) to aquifers
	Stream flow variation (including gain and loss measurements)
Site Information	Previous site use (system operations, materials handled, safety considerations)
	Potential sources of contamination (on and off site)
	Location of buried utilities (contamination source, safety considerations, affect on groundwater flow)
	Location of established monitoring points (including complete construction details for monitoring wells)

well as for identifying possible sources of contamination and pertubations on the local groundwater flow system.

Each of these types of data can provide useful information in the identification and evaluation of the contamination incident. Some may already exist and be available at the Air Force base or from other sources, while some may have to be collected, and some may not be required in response to the contamination incident. The types and level of data detail necessary to address a groundwater contamination incident are problem-specific and can only be determined during the problem assessment. However, a methodology does exist which can be used to select an appropriate response to almost all groundwater contamination incidents. This methodology, summarized in Figure 1, is described in detail in the following paragraphs.

The initial notification of the potential groundwater contamination will provide the first information regarding the nature and extent of contamination. The notification would probably include at least qualitative information such as taste or odor, for example, and specfic location information. This information will be the base for developing an initial strategy for defining the nature and extent of contamination and selecting an appropriate remedial response.

The first step is to gather the available information and assess the problem. Because it is unlikely that all of the information listed in Table 1 would be available, the initial assessments must be based on interpretations from whatever information is available.

The available geologic and hydrologic information may include published maps of a general nature or it may include data collected as part of other investigations. If data from the specific site are not available, then representative values from similar materials or terrains can be used as an initial approximation. Some of the likely sources of geologic and hydrologic data have been identified in the Volume II of this report.

The geologic information should be summarized to prepare a three-dimensional representation of the site. This is done to identify the relationships between the various hydrologic unit(s) and to identify those units most likely to be affected by the contaminant. Maps showing the areal distribution and variations in thickness and water-transmitting properties of the different units and geologic sections showing their vertical relationships are most useful for this purpose.

The available water level information is interpreted to determine groundwater flow directions. This is done by plotting water level information on maps and preparing water table or potentiometric contour maps. Flow directions are determined on the basis of the contour patterns. The estimated groundwater flow directions and water-transmitting properties of the geologic units are used to estimate the rate and direction of contaminant transport and the size of the

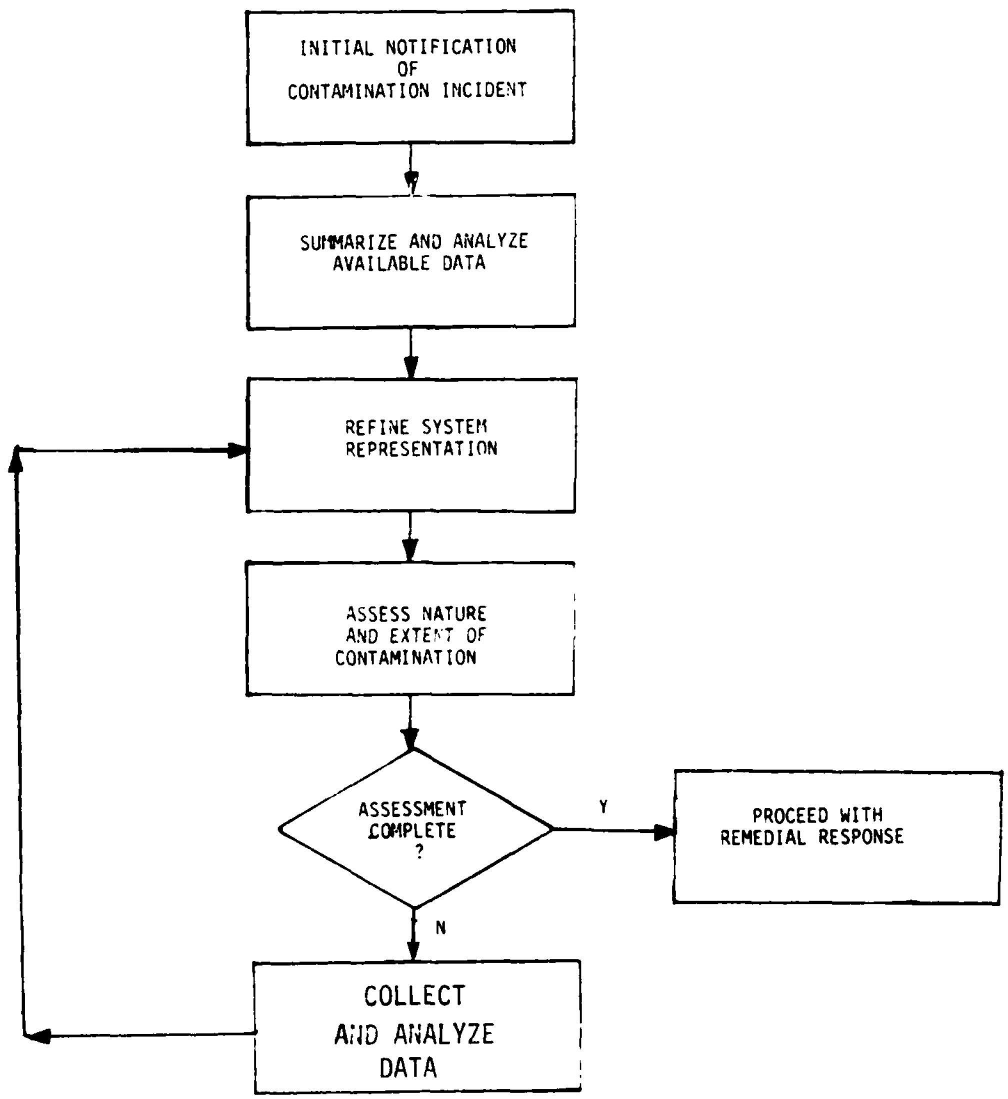


Figure 1. Schematic Representation of Interaction Between Data Analysis, Problem Assessment, and Data Collection Leading to Selection of Remedial Response

contaminant plume. Table 2 includes equations which can be used to calculate transport velocities and contaminant concentrations. These equations are based on simplifying assumptions about the groundwater flow system and contaminant transport, but can be used to estimate contaminant distribution. Input parameter values would be determined from available site data, or representative values for similar materials or terrains could be used to make the initial estimates. The greater the uncertainty for any input parameter, the wider the range of values which should be used in the analyses. These estimates would be evaluated during the subsequent data collection program, and revised according to the new information. Some hydrologic principles which need to be recognized when dealing with contaminant plumes in groundwater are:

- the contaminant plume is not diluted with the entire body of groundwater, but tends to remain as an intact body with only slight dispersion and diffusion along the edges;

- the contaminant actually moves faster than the average groundwater velocity because of hydrodynamic dispersion;

- the path of a soluble contaminant plume will generally follow the direction of groundwater flow. Diversions in flow direction from induced changes in gradient (e.g., a pumped well) will also divert the contaminant plume;

- the flow direction of a water-immiscible contaminant will be affected by the groundwater flow direction, but they do not necessarily coincide;

- hydraulic and lithologic conditions and fluid density determine the vertical depth to which the contaminant will migrate into the aquifer. The thickness of the plume in the aquifer will probably increase with distance downgradient from the source;

- the extent and movement of various constituents in the contaminant plume will vary depending on attenuation from the various chemical and biochemical reactions.

The initial contamination assessment should attempt to identify the particular chemical or contaminant and identify all possible sources of the contamination. Initial assessments should also be used for screening the remedial alternatives to identify those likely to be effective.

TABLE 2. EQUATIONS FOR ESTIMATING CONTAMINANT TRANSPORT VELOCITIES AND CONTAMINANT CONCENTRATIONS FOR IDEALIZED FLOW SYSTEMS

	POROUS MEDIA	FRACTURED MEDIA
BULK FLOW	$\overline{V} = (K/n)\ (\Delta h/L)$	$\overline{V} = (K/Nb)\ (\Delta h/L)$
WITH RETARDATION	$V_c = \overline{V}/(1 + (\rho b \cdot Kd)/n)$	$V_c = \overline{V}/(1 + (2\ Ka/b))$
WITH DISPERSION	$(C/C_o) = (0.5)\ (\mathrm{erfc}\ (L-Vt)/(2\sqrt{D_L t}))$	NA

where

V is the average linear velocity of the fluid

K is the hydraulic conductivity

n is the effective porosity

$\Delta h/L$ is the headgradient between two points

N is the number of fractures per unit distance

b is the width of the fractures

V_c is the velocity of the 0.5 point on the concentration profile of the retarded species

ρb is the bulk mass density of the porous medium

Kd, Ka are the distribution coefficients of the contaminant for porous and fractured media, respectively

TABLE 2. (CONCLUDED)

C is the contaminant concentration at a point X_i

C_o is the source concentration of the contaminant

l is the distance along the flow path from the source to the point where C is calculated

t is the time since the contaminant entered the groundwater system

D_l is the coefficient of longitudinal hydrodynamic dispersion

2. ADDITIONAL DATA COLLECTION AND ASSESSMENT

a. Field Investigations

After analysis of available data and estimates of the probable source, nature and extent of contamination, a field investigation program is implemented to evaluate initial estimates, as well as gather additional hydrogeologic information about the site. Table 3 lists field investigation activities which might be undertaken to improve the information base. Selection of field investigation methods is based upon the type and amount of additional data needed to supplement the available information. These methods have been described in the Desk Reference (Volume II) and are summarized below.

TABLE 3. FIELD INVESTIGATION ACTIVITIES WHICH CAN BE UNDERTAKEN TO IMPROVE THE INFORMATION BASE FOR CONTAMINATION ASSESSMENT

- Field Mapping
- Surface Geophysical Surveys
- Test Drilling and Sampling
- Monitor Well Installation
- Borehole Geophysical Surveys
- Hydraulic Testing
- Water Quality Sampling

(1) Field Mapping

Field mapping can be done on a topographic or aerial photographic base. The maps and photos are used to accurately identify the locations of various surface features and the different geologic units. Identifying the location of surface features, such as springs, seeps, streams, sampling points, and cultural features can facilitate problem identification. Comparisons of present and past aerial photographs may provide information regarding changes in land use or base operations which may help to identify the source of contamination.

(2) Surface Geophysical Surveys

The two most common types of surface geophysical surveys are electrical earth resistivity and seismic refraction surveys. Both of these methods provide geologic interpretation based on indirect measurements of physical characteristics. They can provide subsurface geologic information much faster and cheaper than drilling, but they must be calibrated against more direct measurements. They can also be used in areas which may not be accessible to a drilling rig.

Earth resistivity surveys are commonly used to define subsurface geology and, occasionally, zones of contaminated groundwater. In complex geologic environments or in the vicinity of some manmade

structures, such as buried pipelines and fences, the results of a resistivity survey are inconclusive. Seismic surveys are generally used to provide information regarding the depths and thicknesses of different geologic units, as well as depth to water. The results of these surveys can also be difficult to interpret in complex environments. Other surface geophysical surveys which provide more specialized information have been described in the Desk Reference.

(3) Test Drilling and Sampling

A test drilling and sampling program is often necessary to describe the local hydrogeologic environment. This includes the type, thickness and depth of the various geologic units, their water-bearing and chemical characteristics, and depth to water. Samples may be collected to provide visual identification of the materials encountered, or they may be collected for specialized laboratory tests. The drilling and sampling method used depends upon the type and depth of material to be sampled. Several drilling and sampling methods have been described in Section IV of the Desk Reference. Drilling methods vary on a regional basis because of the large scale variation in geologic conditions. Discussions with local drillers can provide information regarding the drilling techniques used locally.

Samples of geologic materials can also be obtained when they are exposed at land surface, such as quarries, sand and gravel pits and bedrock outcrops. Because of weathering, however, the samples collected from land surface may not be representative of conditions below ground, particularly for bedrock materials.

(4) Monitor Well Installation

It is frequently desirable to install monitoring wells during the test drilling and sampling program. Monitoring well locations are usually chosen after analysis of available information. The expense associated with well construction materials and installation, maintenance, and operation of the monitoring network, necessitates careful selection of monitoring well locations.

Monitoring sites are usually chosen to provide information regarding temporal changes in water levels or quality, to document the presence or absence of a contaminant or to provide early warning of an unexpected change in direction of movement or size of the contaminant plume. The specific data that should be evaluated in designing the monitoring network include:

- groundwater flow direction;
- distribution of geologic and hydrologic characteristics of various units
- background water quality;

- present or future effects of groundwater withdrawals on the flow system;

- the type and frequency of measurements to be made at the monitoring site, as well as the expected temporal variation in those parameters.

The information provided by a monitoring well represents a small portion of the geologic unit being sampled. Interpolation of the information collected from the well to the geologic material in general is frequently limited by the heterogeneity of the material. The greater the geologic variability, the larger the number of sampling points necessary to adequately define the subsurface environment.

(5) Borehole Geophysical Surveys

The most commonly used borehole geophysical surveys in groundwater contamination assessments are resistivity and natural gamma logging. These surveys generally provide qualitative information regarding the variations in geologic materials (resistivity and natural gamma logging) and water quality (resistivity logging). These surveys are usually used to supplement the driller's and geologists' log of the test drilling operation.

Resistivity surveys can only be made in uncased boreholes and, therefore, may not be possible for all test holes. Natural gamma surveys do not have that restriction and are particularly useful for interpreting lithologic information from previously drilled wells for which this information is not available.

(6) Hydraulic Testing

Hydraulic testing is usually done to determine in-situ hydraulic properties. Tests can be done using single or multiple wells or piezometers. These field methods are based on analyzing water level changes in wells or piezometers in response to a sudden introduction or removal of a known volume of water or to an instantaneous pressure pulse. Single well tests provide in-situ values of hydraulic properties which represent a small volume of the aquifer, while multiple well tests provide values that represent a larger portion of the aquifer. The hydraulic properties are frequently determined by comparing observed water test level changes with those calculated for idealized aquifer geometries.

In-situ tests may provide information regarding the hydraulic properties of the geologic media in the immediate vicinity of the contamination problem. A disadvantage to this field technique is that the analysis of the water level change data is usually not straightforward. In particular, observed water level change data are affected by well contruction and aquifer geometry and heterogeneity. Misrepresentation of either of these parameters will yield erroneous results.

(7) Water Quality Sampling

Water samples are collected to obtain information regarding natural variations in water quality, as well as to determine areas which are contaminated. Samples may be collected from surface water bodies or from the groundwater system. Groundwater samples can be collected from existing wells or springs, during test drilling activities, or from monitoring wells installed as part of the field investigation.

The objective of the water quality sampling program should be to collect and preserve water samples so that the water quality of the sample is representative of the environment from which it was collected. This is not a trivial task because the techniques which can be used to obtain a sample are often limited by the ease of access to the sampling point. For groundwater samples, the major limitations are commonly the depth to water and well diameter. Table 4 lists some of the common sampling methods used for various well diameters and depths to water. Sampling methods are described in Section IV(4) of the Desk Reference.

b. Chemical Analysis Methods

(1) Overview

During the analysis of groundwater and sediment samples for organic and/or inorganic constituents, it is necessary to follow some steps fundamental to the analytical process. These steps are as follows:

- obtain a representative sample;
- prepare the sample for analysis;
- separate constituent(s) that interfere;
- identify/measure the constituent(s) of interest in the sample;
- calculate the results including, as appropriate, precision, accuracy and detection limits of numerical results.

The purpose for obtaining a representative sample in the field was discussed in paragraph b(1), Section II, of this report. Once a field sample has been received in the laboratory, it is usually necessary to obtain a representative aliquot of that field sample for subsequent analysis. Representative aliquots from groundwater samples are typically obtained by constructing a composite field sample using homogenization (a blender) or shaking (by hand), and quickly withdrawing an appropriately sized aliquot from the composite field sample.

Successfully implementing steps 2, 3, and 4 of the analytical process depends upon selecting appropriate analytical techniques. In turn, selection of those techniques is based on what is known about the

TABLE 4. PUMPING EQUIPMENT SELECTION

Diameter Casing	Bailer	Peristaltic Pump	Vacuum Pump	Airlift	Diaphragm "Trash" Pump	Submersible Diaphragm Pump	Submersible Electric Pump	Submersible Electric Pump w/Packer
1.25-inch								
Water level < 20 ft		X	X	X	X			
Water level > 25 ft								
2-inch								
Water level < 20 ft	X	X	X	X	X	X		
Water level > 25 ft	X			X	X			
4-inch								
Water level < 20 ft	X	X	X	X	X	X	X	X
Water level > 25 ft	X			X		X	X	X
6-inch								
Water level < 20 ft				X	X		X	X
Water level > 25 ft				X			X	X
8-inch								
Water level < 20 ft				X	X		X	X
Water level > 20 ft				X			X	X

source of the sample and what the ultimate use of the data will be. Selection of analytical techniques is discussed later in this section. Data gathered during a sampling and analysis program may vary in quality. For the purposes of this report, quality refers to the validity, reliability and, more specifically, the precision and accuracy of the data.

To ensure the generation of high quality data for groundwater samples, a Quality Assurance/Quality Control (QA/QC) program should be implemented throughout a sampling and analysis program. In addition, the user of data generated during a groundwater sampling and analysis program should have sufficient information about the original method of analysis and the data quality to assess whether or not the data meet the purposes of the program. Use of a QA/QC program ensures that the quality of data is documented in a way that permits users of the data to make independent assessments. The basic elements of a QA/QC program are discussed later in this section.

(2) General Approach

Before analysis of field samples, it is necessary to prepare an analytical plan directed towards solving the specific problem. Development of this plan with appropriate selection of analytical methods requires review of information concerning the intended purpose of the data, and previously obtained data.

The methods selected for the analysis of groundwater and sediment samples must be appropriate for the purpose of the chemical analysis data. The following criteria for the analytical method should be used: adequate sensitivity, detection limits, selectivity, precision and accuracy. Other characteristics that should be considered include: dynamic measurement range; ease of operation; multiconstituent applicability; low cost; ruggedness; portability. For example, when chemical analysis data is to be used to demonstrate compliance with regulatory standards, these standards may require that certain analytical techniques be used, and that particular organic compounds be analyzed at or below specified limits of detection.

Further, available information concerning the samples and the source of the samples must be reviewed in order to provide further input into selecting analytical methods. Preparation and analysis of a sample depends upon the type of sample (groundwater, sediment, interstitial water), the organics being analyzed, and the potential interferences to be dealt with. The chemical composition of the samples may be available through previous analyses, known chemical disposal and management practices, obvious odors, or other means. Chemical composition information may be used to determine what organics are of interest to the study and what interferences are expected to be a problem. The planning stage for selecting an analytical approach is summarized in Figure 2.

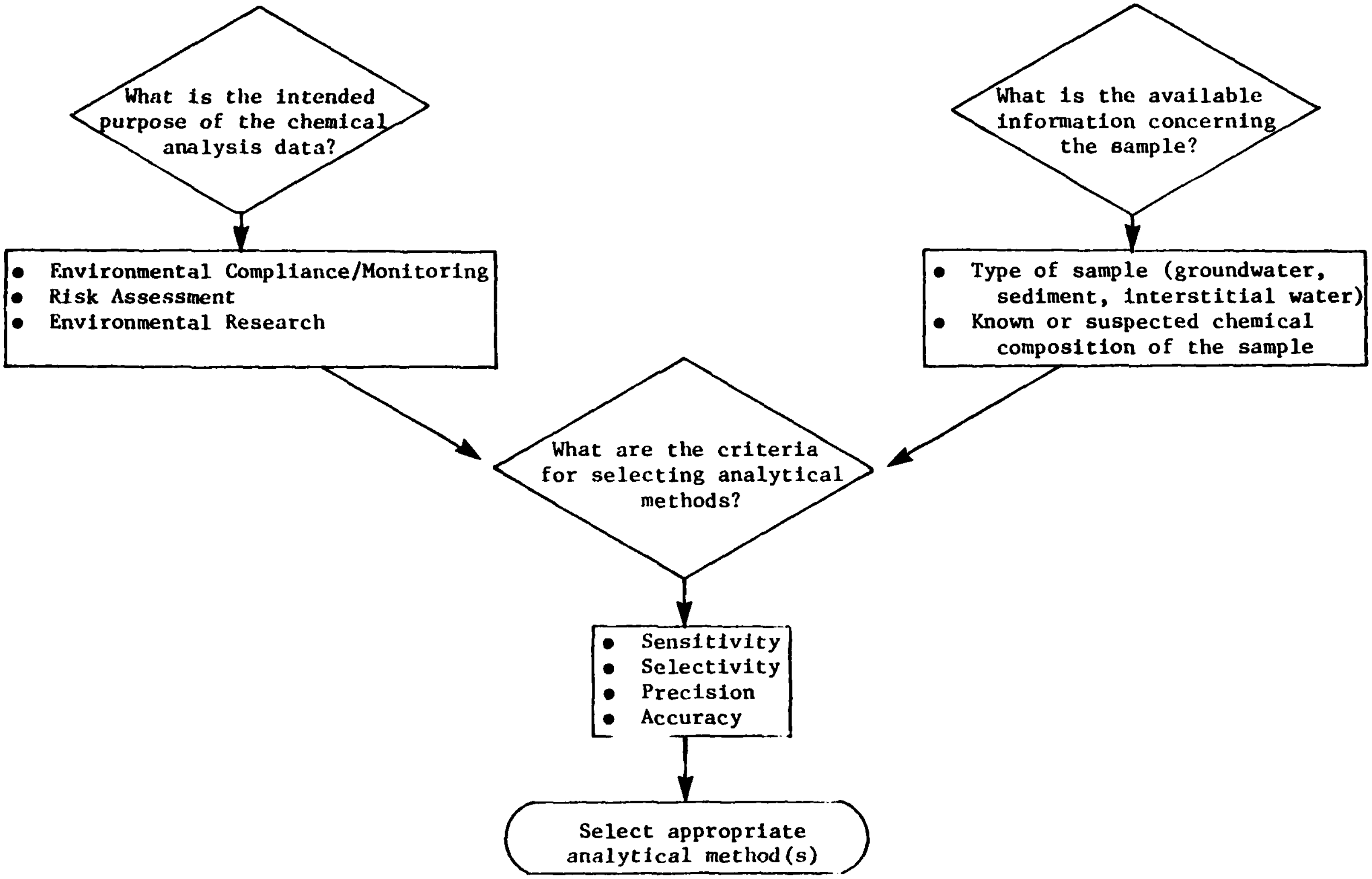


Figure 2. Sel ction of Analytical Methods

When there is uncertainty as to the most appropriate analytical methods, one set or subset of samples should be analyzed and the appropriate statistics calculated to determine the applicability of the methods. If the data from one approach are within the original criteria, then analysis of the balance of the samples may proceed. If the initial data are determined to be unsuitable, then it is necessary to either change or modify the analytical procedures. This process for determining the applicability of the analytical plan is shown in Figure 3.

(3) Methods for Organic Chemicals

The organic content of groundwater, sediment, and interstitial water may be approximated through analysis of the classical parameters given in Figure 4. The data obtained from these analyses do not provide the identity and concentration of specific organic compounds. However, such information can be useful since these parameters have been extensively used as indicators of water quality. There is, therefore, a large data base available for comparison. Of the conventional parameters, total organic carbon (TOC) and total organic halogens (TOH) are the most useful. TOC and TOH are rapid, cost-effective measurements which provide an assessment of organics in the samples. They are useful in the assessment of the level of contamination of a sample, and the subsequent determination of the procedures necessary for sample preparation and measurement of specific organic compounds. For example, if a TOC value is high, it may be desirable to dilute the sample prior to a particular measurement to prevent overloading the detector. The results of TOC and/or TOH analyses should not be used to determine whether or not a sample is hazardous, since some organic chemicals may be present at extremely low concentrations (below the detection limits for TOC and TOH) and the data from TOC and TOH analyses will not indicate their presence.

(4) Other Classical Parameters

After review of the classical water parameter tests, the next step in selection of a method is the determination of the organic species of interest. A directed analysis may be performed for a particular species, or if the organics present have not been identified, a screening analysis may be performed. Directed analyses are designed to provide qualitative confirmation of presence and compound identities, as well as quantitative data of known quality for each of the specified organics of interest. A screening analysis is designed to provide an overall description of the major types and approximate quantities of organics present in the sample. The results of a survey analysis may lead to subsequent directed analyses.

A comprehensive scheme for directed and/or survey analyses is given in Figure 5. This scheme does not include all the possible analytical techniques which may be used when characterizing a sample, however, it does include the more commonly utilized approaches. A more complete description of analytical methods is included in Volume II.

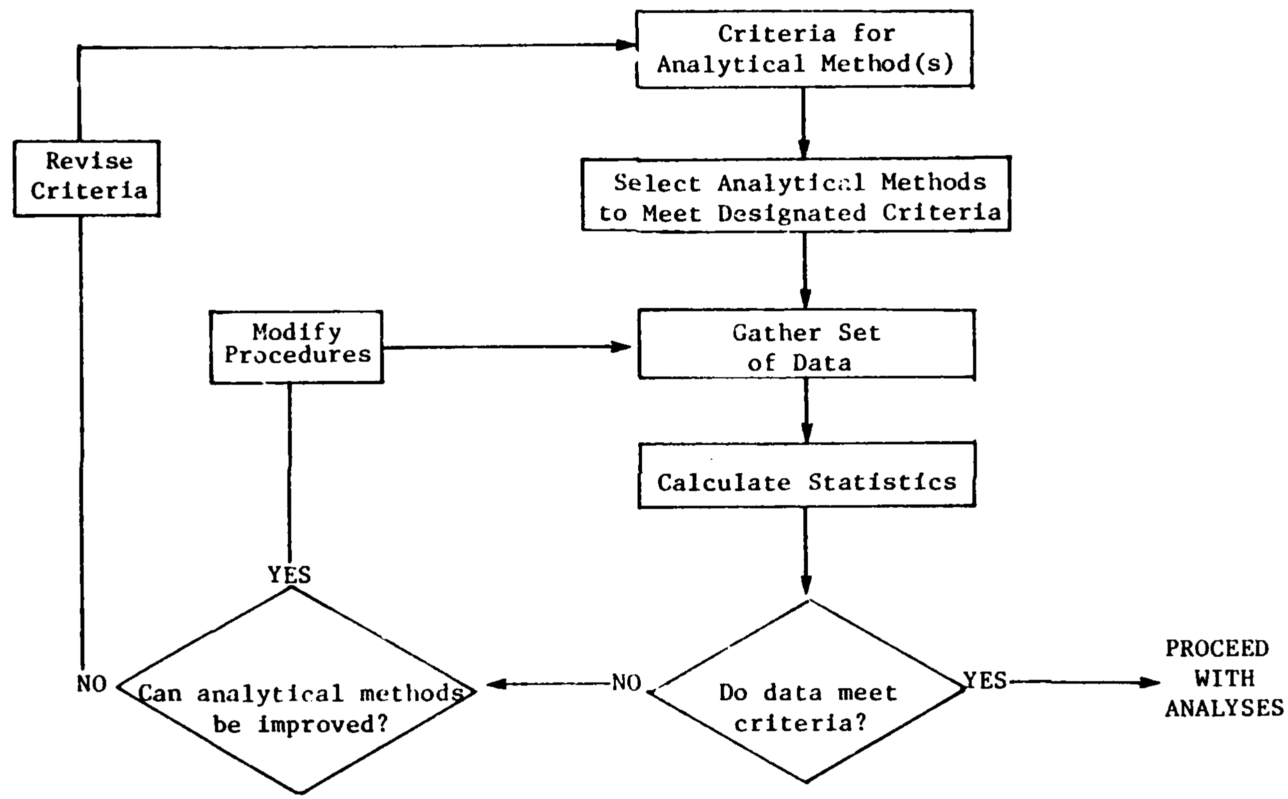


Figure 3. Applicability of the Analytical Plan

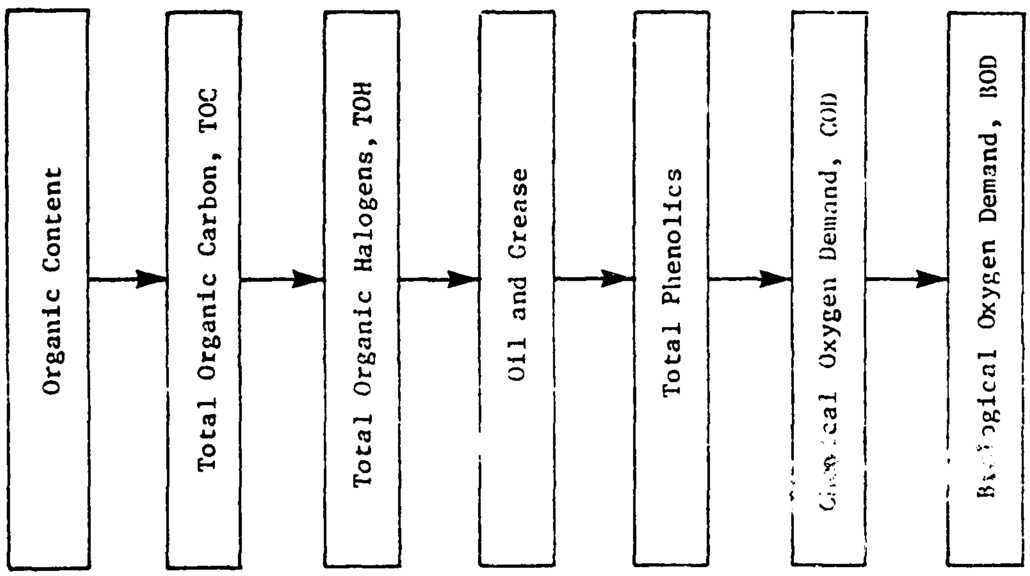
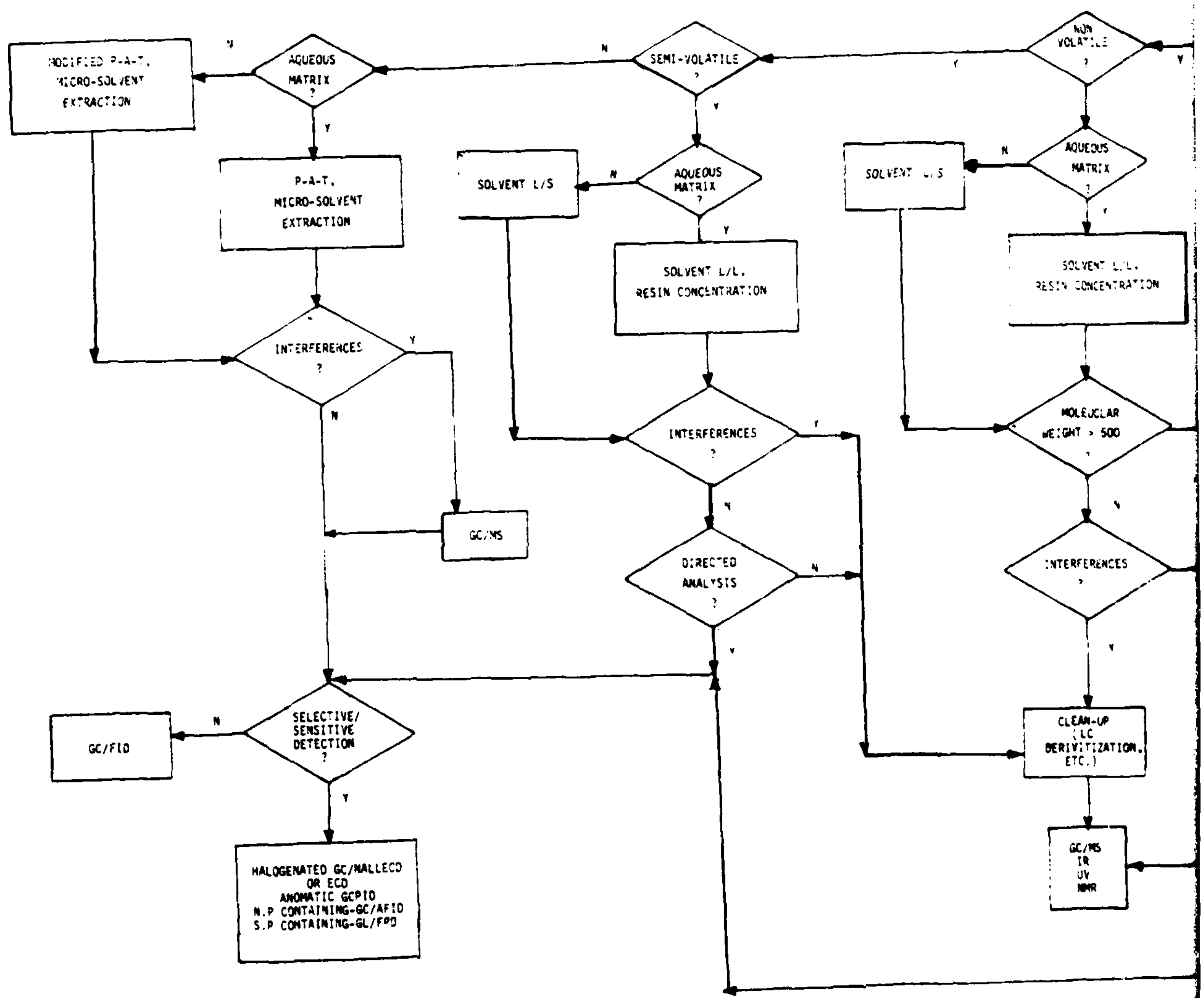


Figure 4. Analyses Parameters


MODIFIED P-A-T, MICRO-SOLVENT EXTRACTION
AQUEOUS MATRIX ?
SEMI-VOLATILE ?
NON VOLATILE ?
P-A-T, MICRO-SOLVENT EXTRACTION
SOLVENT L/S
AQUEOUS MATRIX ?
SOLVENT L/S
AQUEOUS MATRIX ?
SOLVENT L/L, RESIN CONCENTRATION
SOLVENT L/L, RESIN CONCENTRATION
INTERFERENCES ?
INTERFERENCES ?
MOLECULAR WEIGHT > 500
GC/MS
DIRECTED ANALYSIS ?
INTERFERENCES ?
GC/FID
SELECTIVE/ SENSITIVE DETECTION ?
CLEAN-UP (LC DERIVITIZATION, ETC.)
GC/MS IR UV NMR
HALOGENATED GC/HALLECD OR ECD
AROMATIC GCPID
N.P CONTAINING-GC/AFID
S.P CONTAINING-GL/FPD
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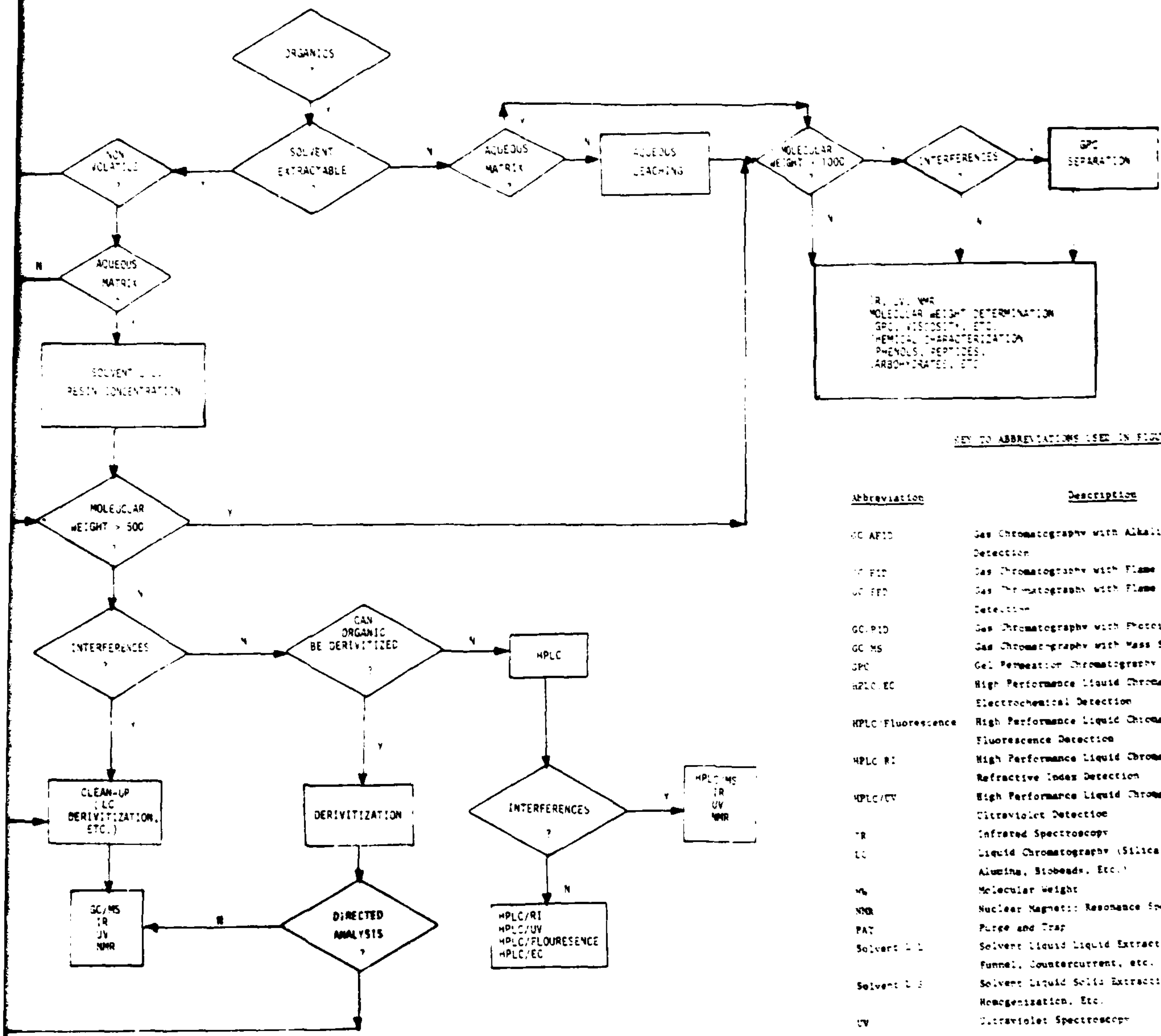

KEY TO ABBREVIATIONS USED IN FIGURE 5

Abbreviation	Description
GC/AFID	Gas Chromatography with Alkali Flame Ionization Detection
GC/FID	Gas Chromatography with Flame Ionization Detection
GC/FPD	Gas Chromatography with Flame Photometric Detection
GC/PID	Gas Chromatography with Photoionization Detection
GC/MS	Gas Chromatography with Mass Spectroscopy
GPC	Gel Permeation Chromatography
HPLC/EC	High Performance Liquid Chromatography with Electrochemical Detection
HPLC/Fluorescence	High Performance Liquid Chromatography with Fluorescence Detection
HPLC/RI	High Performance Liquid Chromatography with Refractive Index Detection
HPLC/UV	High Performance Liquid Chromatography with Ultraviolet Detection
IR	Infrared Spectroscopy
LC	Liquid Chromatography (Silica Gel, Florisil, Alumina, Biobeads, Etc.)
MW	Molecular Weight
NMR	Nuclear Magnetic Resonance Spectroscopy
PAT	Purge and Trap
Solvent L/L	Solvent Liquid Liquid Extraction (Separatory Funnel, Countercurrent, etc.
Solvent L/S	Solvent Liquid Solid Extraction (Soxhlet, Homogenization, Etc.
UV	Ultraviolet Spectroscopy

Figure 5. An Example of a Comprehensive Analytical Scheme for Organic Contaminants Which May be Found In Groundwater

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(5) Quality Assurance/Quality Control

The implementation of a Quality Assurance/Quality Control (QA/QC) Program during a sampling and analysis program is critical to providing reliable analytical results. A QA/QC program provides procedures and guidelines to:

- ensure data of the highest quality possible;
- maintain the quality of data within predetermined (tolerance) limits and to provide specific guidelines for activities to be taken where those predetermined limits are exceeded;
- document the quality (accuracy and precision) of generated data.

A QA/QC program addresses several areas. These include:

- Personnel responsibilities
- Documentation
- Data and procedures reviews
- Audits
- Maintenance of facilities and equipment
- Training
- Sample preservation
- Standards and reagents
- Chemical analysis methods
- Quality control samples
- Quality control data

c. Integrating Data Collection and Analysis

The initial data analysis and problem assessment will provide information regarding the types of data that may need to be collected during the field investigation program. These data needs will reflect the uncertainties in the interpretation of the available data as well as the short and long term goals of assessing the degree of contamination and selecting a remedial response plan. It should not be expected, however, that the data needs required for complete problem assessment can be determined during the initial problem analysis. Some of the data needs may be satisfied with a limited amount of additional data collection, but it should be anticipated that the data collection activities may identify new uncertainties or data needs which require more data collection. The data collection effort should be planned, therefore, to provide for periods of data analysis in order to redefine and establish priorities for data collection. After the data needs have been redefined the data collection program should be redone to provide for collecting the most critical data in a timely manner. Figure 6 illustrates the sequence of steps to be followed when integrating the data collection and analysis efforts.

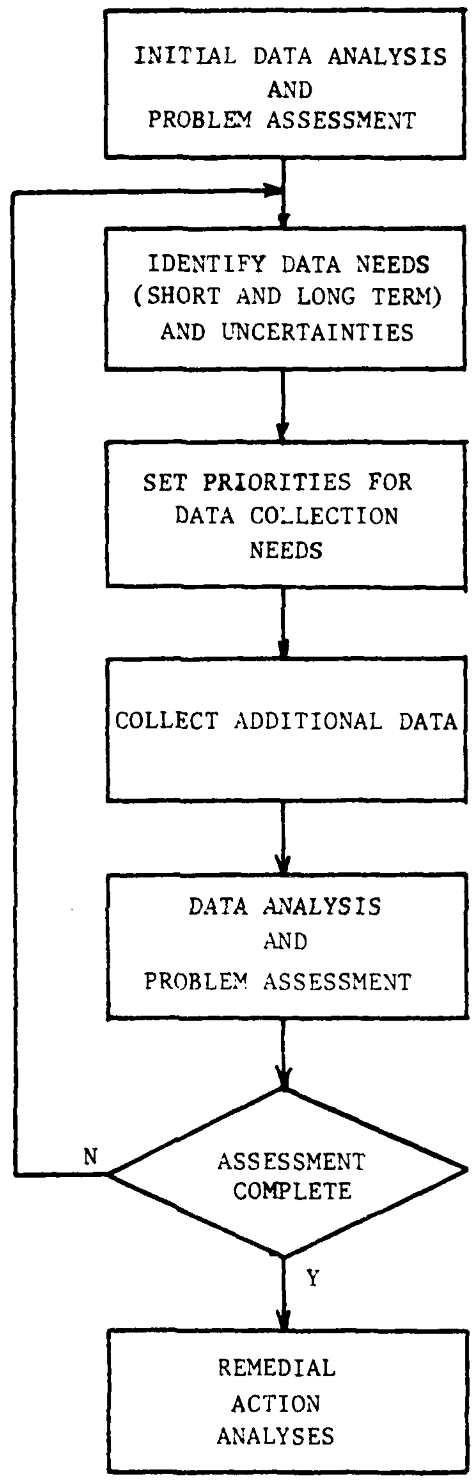

Figure 6. Schematic Illustration of the Interaction Between Data Collection and Analysis

SECTION III

DEVELOPING DECISION PARAMETERS

1. ULTIMATE FATE OF ORGANICS IN GROUNDWATER

This section describes a two-step procedure to obtain information on the ultimate fate of organic chemicals in the soil/groundwater system. It identifies the information needs and provides direction for obtaining such information and using it for an assessment of ultimate fate.

A key aspect of this approach is an initial (preliminary) assessment making use of readily available data, supplemented with estimates and/or surrogates (Figure 7). The purpose of this initial step is twofold: (1) to provide a more rapid, preliminary analysis - avoiding the time and expense of laboratory and field studies - so that timely decisions and plans can be made, e.g., on response actions; and (2) to provide a sharper focus on just what additional laboratory and field tests - if any - need to be done. While the use of such a procedure should save both time and money, there is no formal requirement for its use, and some conditions may warrant a different approach.

Key sections of Volume II that will be referred to are:

- Fate of organic groundwater pollutants (Section III(f)); and
- Physical, chemical, and biological parameters and constants applicable to organic contaminants and physical systems of concern (Section V(a)).

a. Step I - Preliminary Assessment

(1) Information Requirements

Section V(1) of Volume II provides a discussion of important chemical-specific (cf. Table 23) and environment-specific (cf. Table 24) properties.

Perhaps the chemical-specific properties are more important to evaluate in the preliminary assessment. However, without detailed knowledge of certain environment-specific properties, it may not be possible to determine the correct value(s) of some chemical-specific properties within an order of magnitude. For example, the soil adsorption coefficient will vary with soil type (especially soil organic carbon content) and other parameters. An order-of-magnitude uncertainty may be quite acceptable in a preliminary assessment considering (as described in Section III(f) of Volume II) that many of these properties range over at least seven orders of magnitude and that the importance of a fate process may be associated with a wide range of a property.

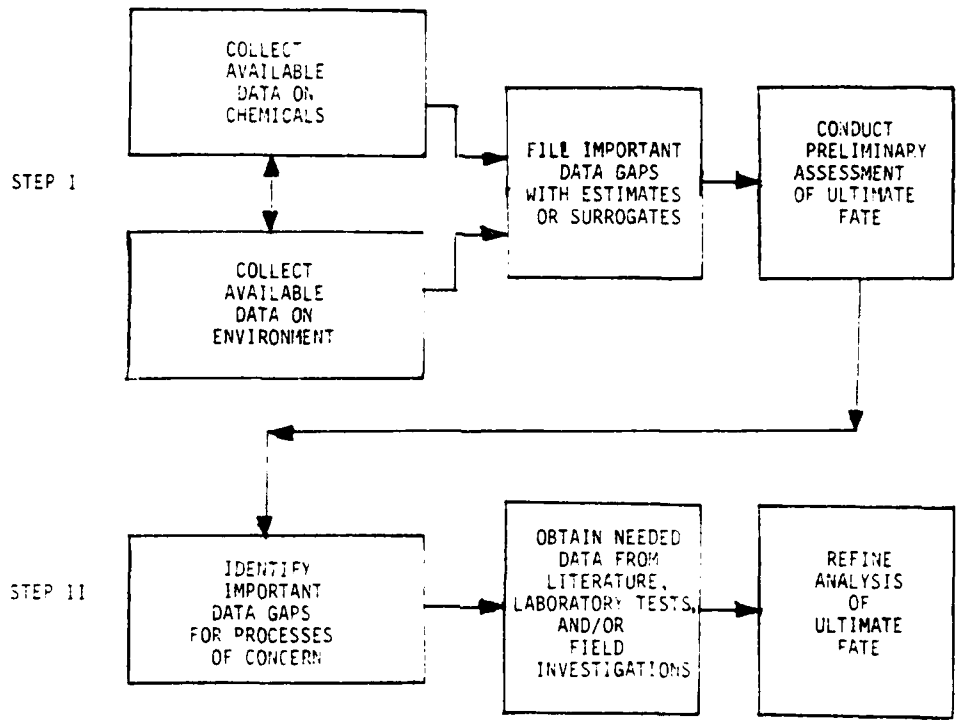

Figure 7. Two-Step Process for Assessing the Ultimate Fate of Organics in Groundwater

Measured values of the chemical-specific properties are much preferred over estimates; however, data have been published for only a relatively small fraction of the more common pesticides, solvents, fuel constituents, and other synthetic chemicals. This is especially true for persistence-related properties (e.g., rate of hydrolysis, rate of biodegradation). Because much of the important literature is widely scattered (i.e., in different books, journals, government reports, and unpublished reports), often confusing (due to the use of different test methods), and of variable quality, a literature search by a qualified, experienced environmental scientist is required. Such searches cannot rely on computer searches of bibliographic data bases because of the nature of the sources containing the data and the manner in which they are abstracted. Computerized data bases of physical and chemical properties are just starting to become available, but, at the present, have not proven their worth.

If measured values of the chemical-specific properties are not available, reasonable estimates may frequently be derived. (See Lyman et al., 1982.)

Environment-specific properties may be available in literature describing the geohydrological and meteorological conditions near the site. Possible sources of additional information are described later in this report.

As described in the overview, it is suggested that a preliminary assessment proceed without recourse to special, often expensive, laboratory or field tests to fill all data gaps.

(2) Assessment of Fate

The first 'law' of environmental pollution states that: "Everything must go somewhere." An assessment of the ultimate fate of a groundwater pollutant should answer two questions following logically from this law: a. "Where does it go?" and b. "How fast does it get there?" Both of these questions may reasonably be asked with regard to three types of processes:

- partitioning of the chemical between the three phases (soil, water, air) of the 'soil';
- degradation of the chemical by such processes as hydrolysis, biodegradation, and oxidation; and
- transport of the chemical, either in the vapor phase to the atmosphere or in solution with the groundwater.

The answers for the third type of process (transport) usually require modeling which may be beyond the resources and data availability associated with a preliminary assessment.

For partitioning, the preliminary assessment should determine (predict) how the chemical partitions between the soil, water, and air phases of the groundwater system. Section III(b) of Volume II provides a technical discussion of the methodology. This answers the question "Where does it go?" and provides important information on the mobility of the chemical. The question of "how fast?" is seldom important for partitioning since the time scales of groundwater movement are usually much longer than the time required for equilibrium partitioning to be achieved.

For degradation, the question of "how fast?" should come first. This refers to assessing the rates at which the chemical is transformed (degraded) from its original form to some other compound, or series of compounds, by the processes mentioned. The answers will be in the form of rate constants and will be environment-specific (i.e., will depend on such properties as temperature and pH). The question of "Where does it go?" is translated in this case to "What are the products of degradation?" The answer to this question will include a list of "intermediate" and "final" (stable) chemicals which will also be environment-specific in many cases. Information on the degradation products is important for assessments of potential human health effects and for monitoring programs. Section III(3) of Volume II provides background information on this subject.

b. Step II - Revised Assessment

The preliminary assessment should have provided an identification, and possibly even a semiquantitative description, of the important fate processes acting on the chemicals of concern. It will also have, almost certainly, identified a number of important data gaps for both chemical- and environment-specific properties. The revised assessment will require more detailed knowledge about the key chemical- and environment-specific properties and the factors affecting their values. Although some of these data may be found after specialized literature searches, laboratory and/or field tests will usually be required. These tests will often require considerable time (weeks to months) and expense.

A hypothetical example may help to illustrate the process. Assume that a preliminary assessment for a chemical indicated that: (1) only water-soil partitioning was important, but the soil adsorption coefficient estimated for the soils at the site was uncertain by a factor of 10; (2) hydrolysis was the only important degradation pathway, but the rate constant, extrapolated from laboratory data obtained under much different conditions, was uncertain by a factor of 100; and (3) only partial information on the hydrolysis reaction products was available. In this case, laboratory tests - using site-specific conditions (soils, water, temperature, etc.) - could provide measured values of the adsorption coefficient and hydrolysis rate constant (as a function of key environmental variables) whose uncertainties were closer to 10 percent. Details on reaction pathways and products would also be available, and a revised fate assessment could be made with confidence.

2. TYPES OF REMEDIAL RESPONSE

The National Oil and Hazardous Substances Contingency Plan (NCP) (40CFR Part 300) identifies three general categories of remedial response. These are:

- initial remedial measures;
- source control remedial actions; and
- offsite remedial action.

Initial remedial measures are actions which are "feasible and necessary to limit exposure or threat of exposure to a significant health or environmental hazard and . . . are cost effective . . . and should begin before final selection of an appropriate remedial action," (40CFR 300.68(e)(1)). They are, in short, cost-effective measures to protect the public and the environment while long term solutions are being sought.

Source control remedial actions are appropriate when "the threat can be mitigated and minimized by controlling the source of the contamination at or near the area where the hazardous substances were originally located," (40CFR 300.68(f)). Removal or repair of a leaky underground fuel storage tank are examples of source control remedial action.

Offsite remedial actions are appropriate when "the hazardous substances have migrated from the area of their original location," (40CFR 300.68(f)). An impermeable barrier, such as a slurry wall, placed underground to contain a contaminated plume while it is being pumped for treatment is an example of offsite remedial action.

Technologies available for remedial action of groundwater contamination may be useful in any of these three categories, depending on site-specific conditions. Groundwater pumping, for example, may be used to protect drinking water supply wells (initial), remove contaminated groundwater at or near the site (source control), or purge a contaminated plume downgradient from the site (offsite). Remedial measures applicable to the treatment, containment, and control of groundwater contamination are discussed in Section VI of Volume II. A comprehensive list of technologies more generally applicable to all types of remedial action is given in the NCP (40CFR 300.70).

SECTION IV

SELECTING A REMEDIAL RESPONSE

Part 300.68 of the NCP details the thought process recommended for selecting an appropriate remedial response. This process, diagrammed in Figure 8, involves four basic steps:

- preliminary assessment;
- development of alternatives;
- analysis of alternatives; and
- selection of appropriate response.

Each of these steps is discussed below with respect to response to groundwater contamination at Air Force facilities.

1. PRELIMINARY ASSESSMENT

Preliminary assessment of the remedial response includes scoping, determination of appropriate type or types of response, and the remedial investigation.

Scoping can be considered the initial assessment of the magnitude of the problem based on available information. Its purpose is to determine expected funding requirements and types of remedial action necessary, and to provide a starting point for remedial investigation. Factors used in scoping are given in Part 300.68(e) of the NCP and summarized in Table 3. The problem assessment phase should be planned so that information required to address these factors is collected.

The remedial investigation is a more detailed analysis of the conclusions of the scoping process. According to the NCP, the remedial investigation has two purposes (40CFR 300.68(f)):

- "to determine the nature and extent of the problem presented by the release," and

- to gather "sufficient information to determine the necessity for and proposed extent of remedial action."

In the context of this report, the first purpose is fulfilled in the problem assessment phase discussed earlier. The remedial investigation considered here fulfills the second purpose. The fact that these two purposes are considered together in the NCP, however, again indicates the importance of considering remedial response information requirements in the problem assessment phase.

Information gathered in the remedial investigation is used to evaluate the conclusions of the scoping process based on the factors given in Table 5. The process is therefore iterative, repeating the

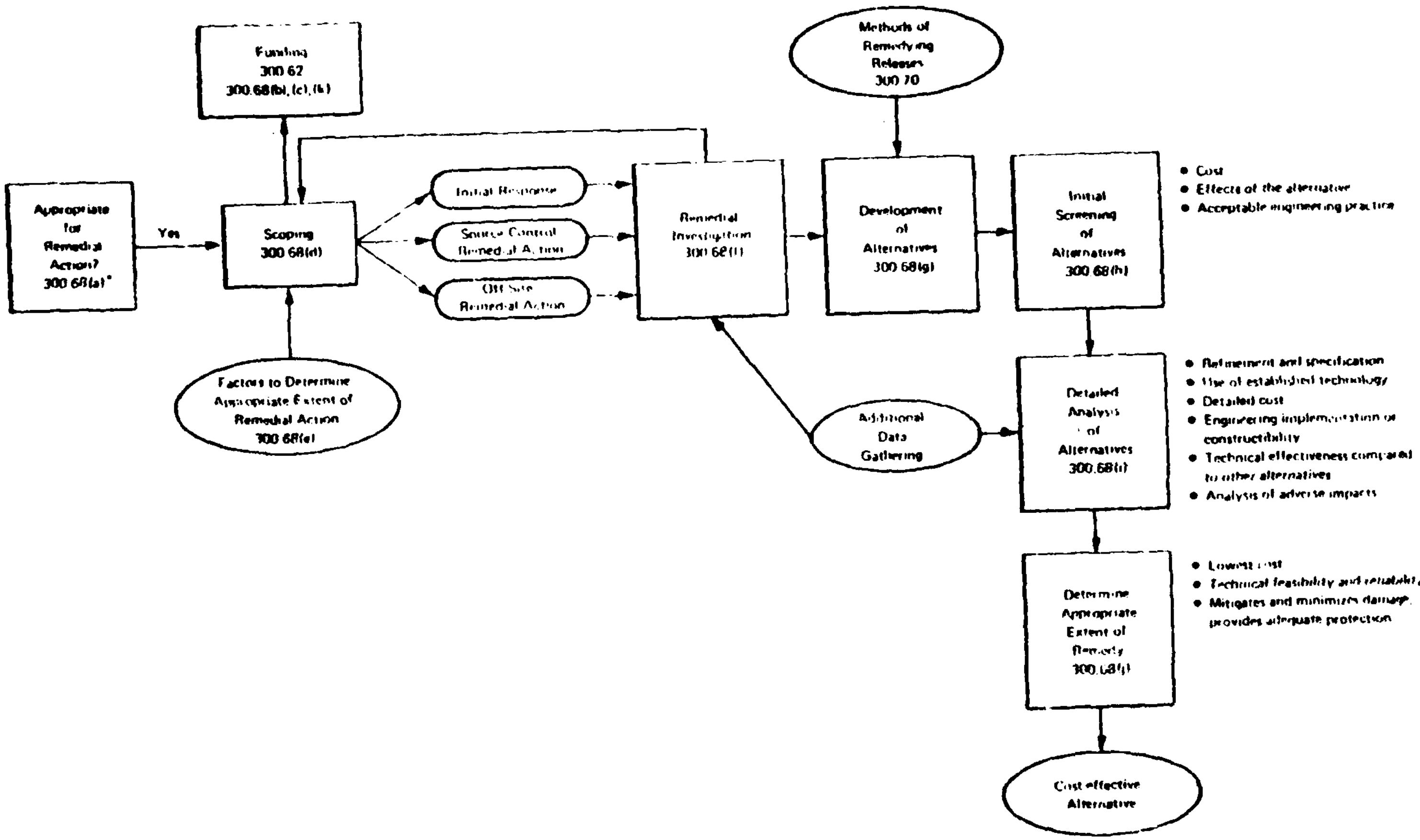

Figure 8. Thought Process for Selecting a Remedial Response (40 CFR 300.68)

Source: Arthur D. Little, Inc. 1982

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TABLE 5. REMEDIAL ACTION CONSIDERATION (40 CFR 300.68(e))

Type of Action	Factors to Consider
Initial Remedial Measures	• Actual or potential direct contact with hazardous substances by nearby population.
	• Absence of an effective drainage control system (with an emphasis on run-on control).
	• Contaminated drinking water at the tap. (Measures might include the temporary provision of an alternative water supply.)
	• Hazardous substances in drums, barrels, tanks, or other bulk storage containers, above surface posing a serious threat to public health or the environment. (Measures might include transport of drums offsite.)
	• Highly contaminated soils largely at or near surface, posing a serious threat to public health or the environment. (Measures might include temporary capping or removal of highly contaminated soils from drainage areas.)
	• Serious threat of fire or explosion or other serious threat to public health or the environment. (Measures might include security or drum removal.)
	• Weather conditions that may cause substances to migrate and to pose a serious threat to public health or the environment.
Source Control Remedial Action	• The extent to which substances pose a danger to public health, welfare, or the environment. Factors which should be considered in assessing this danger include:

TABLE 5. (CONTINUED)

Type of Action	Factors to Consider
	(a) Population at risk; (b) Amount and form of the substance present; (c) Hazardous properties of the substances; (d) Hydrogeological factors (e.g., soil permeability depth to saturated zone, hydrologic gradients, proximity to a drinking water aquifer); and (e) Climate (rainfall, etc.).
	• The extent to which substances have migrated or are contained by either natural or manmade barriers.
	• The experiences and approaches used in similar situations by State and Federal agencies and private parties.
	• Environmental effects and welfare concerns.
Offsite Remedial Action	• Contribution of the contamination to an air, land, or water pollution problem.
	• The extent to which the substances have migrated or are expected to migrate from the area of their original location and whether continued migration may pose a danger to public health, welfare, or environment.
	• The extent to which natural or manmade barriers currently contain the hazardous substances and the adequacy of the barriers.
	• The extent to which substances pose a danger to public health, welfare, or the environment. Factors which should be considered in assessing this danger include: (a) Population at risk; (b) Amount and form of the substance present;

TABLE 5. (CONCLUDED)

Type of Action	Factors to Consider
	(c) Hazardous properties of the substances; (d) Hydrogeological factors (e.g., soil permeability depth to saturated zone, hydrologic gradients, proximity to a drinking water aquifer); and (e) Climate (rainfall, etc.). • The experiences and approaches used in similar situations by State and Federal agencies and private parties. • Environmental effects and welfare concerns.

scoping process until its conclusions are consistent with information gathered in the remedial investigation.

The outcome of the preliminary assessment is a request for funding (as appropriate), a decision on the types of remedial response required, and information necessary to develop alternatives for action. In addition, initial remedial measures may be implemented at this stage.

2. DEVELOPMENT OF ALTERNATIVES

Development of alternatives for remedial action involves selecting a limited number of alternatives "for either source control or offsite remedial actions (or both), depending upon the type of response that has been identified [in the preliminary assessment]" (40CFR 300.68(g)). These alternatives can be selected from the discussion provided in Section VI of Volume II. In addition, a "no-action" alternative may be assessed. "No-action alternatives are appropriate, for example, when response action may cause a greater environmental or health danger than no action," (40CFR 300.68(g)). The no-action alternative was considered by the Air Force in Case History (c) in Volume II. The outcome of this stage is a list of potential alternatives for remedial action to be considered for use at the site.

3. ANALYSIS OF ALTERNATIVES

Once a list of remedial alternatives has been developed, the alternatives must be analyzed so that the most appropriate alternative may be selected. This analysis involves two basic steps:

- initial screening; and
- detailed analysis.

Initial screening of alternatives is designed to eliminate alternatives which are clearly inappropriate to the given situation or are clearly inferior to other alternatives. It is based primarily on three factors:

- cost;
- effects of the alternative; and
- acceptable engineering practice.

Alternatives may be eliminated from consideration on the basis of cost if the alternative "far exceeds (e.g., by an order of magnitude) the costs of other alternatives evaluated and . . . does not provide substantially greater public health or environmental benefit" than other alternatives, (40CFR 300.68(h)(1)).

An alternative can also be eliminated from consideration at this stage if the effect of the "alternative itself or its implementation has any adverse environmental effects" or if the alternative is not "likely to achieve adequate control of source material . . .[nor] effectively mitigate and minimize the threat of harm to public health, welfare, or

the environment," (40CFR 300.68(h)(2)). Groundwater pumping, for example, would not be considered appropriate if pumping would change hydrologic conditions causing contamination of adjacent aquifers.

An alternative may be eliminated from consideration on the basis of acceptable engineering practice if the alternative is not "feasible for the location and condition of release, applicable to the problem, . . . [or does not] represent a reliable means of addressing the problem." Chlorination of groundwater contaminated with organic waste, for example, would not be considered acceptable engineering practice.

Alternatives which remain after initial screening should be evaluated in more detail. This detailed analysis of each alternative should include (40CFR 300.68(i)(2)):

- refinement and specification of the alternative in detail;
- detailed cost estimation, including distribution of costs over time;
- determination of engineering constructability;
- assessment of technical effectiveness; and
- detailed analysis of adverse environmental impacts and methods (with costs) for mitigating these impacts.

Additional data gathering may be required to complete this analysis. In addition, laboratory or pilot scale studies may be required at this stage, particularly for treatment technologies.

4. SELECTING AN APPROPRIATE REMEDIAL ACTION

Based on the results of the detailed analysis, the appropriate alternative(s) for remedial action may be selected. The NCP considers the most appropriate alternative to be "the lowest cost alternative that is technologically feasible and reliable, and which effectively mitigates and minimizes damage to and provides adequate protection of public health, welfare, or the environment," (40CFR 300.68(j)).

The result of this stage is the selection of appropriate cost-effective remedial actions to be implemented at the site. At any step in this process, as new information or data are manifested, it may be necessary to go back to previous steps and consider new types of response and new alternatives for action. This process, however, provides an effective way of approaching groundwater contamination problems to determine the appropriate extent and method of remedial action.

5. RESPONDING TO REGULATORY REQUIREMENTS

Federal regulations for response to groundwater contamination are based primarily on the Resource Conservation and Recovery Act of 1976 (RCRA), and the Comprehensive Emergency Response, Compensation and Liability Act of 1980 (CERCLA or Superfund). These statutes, as well as others which apply to groundwater, are described in Section 2.4 of the Appendix. State and local regulations for response vary from state to state, and from municipality to municipality. Notification requirements based on these regulations are depicted in Figure 9.

Once groundwater contamination is discovered at a site, the source, extent, and other parameters of the contamination should be investigated. Procedures for discovering, investigating, and characterizing groundwater contamination are discussed elsewhere in the report. Notification requirements depend primarily on the location and source of the contamination. Appropriate state and local agencies (e.g., Board of Health, Public Health Department) should be notified if the contamination presents a threat to the local community, or if required by state or local regulation. Contamination discovered at a facility permitted under RCRA requires special notification procedures, dependent on whether the contamination is found upgradient or downgradient of the site. Contamination discovered at a facility not permitted under RCRA may require notification under CERCLA if a "reportable quantity" of waste, as specified in 40CFR 117.3, is determined to have been released. In this case, the National Response Center or designated alternate officials should be contacted. If a quantity less than the reportable quantity has been released, or if the source of contamination is unknown, the National Response Center should be notified to determine appropriate action. These notification procedures are discussed in more detail in Section II(d) of the Volume II.

Response procedures for groundwater contamination at Air Force bases may change because of shifting regulatory policies. In particular, the EPA is currently preparing to give the states the lead role in groundwater protection and is considering giving defense facilities special status with respect to environmental regulations. The RCRA/Superfund Hotline (800-424-9346) can be called for information on new regulations pertaining to RCRA or CERCLA, or to answer questions about recommended response procedures.

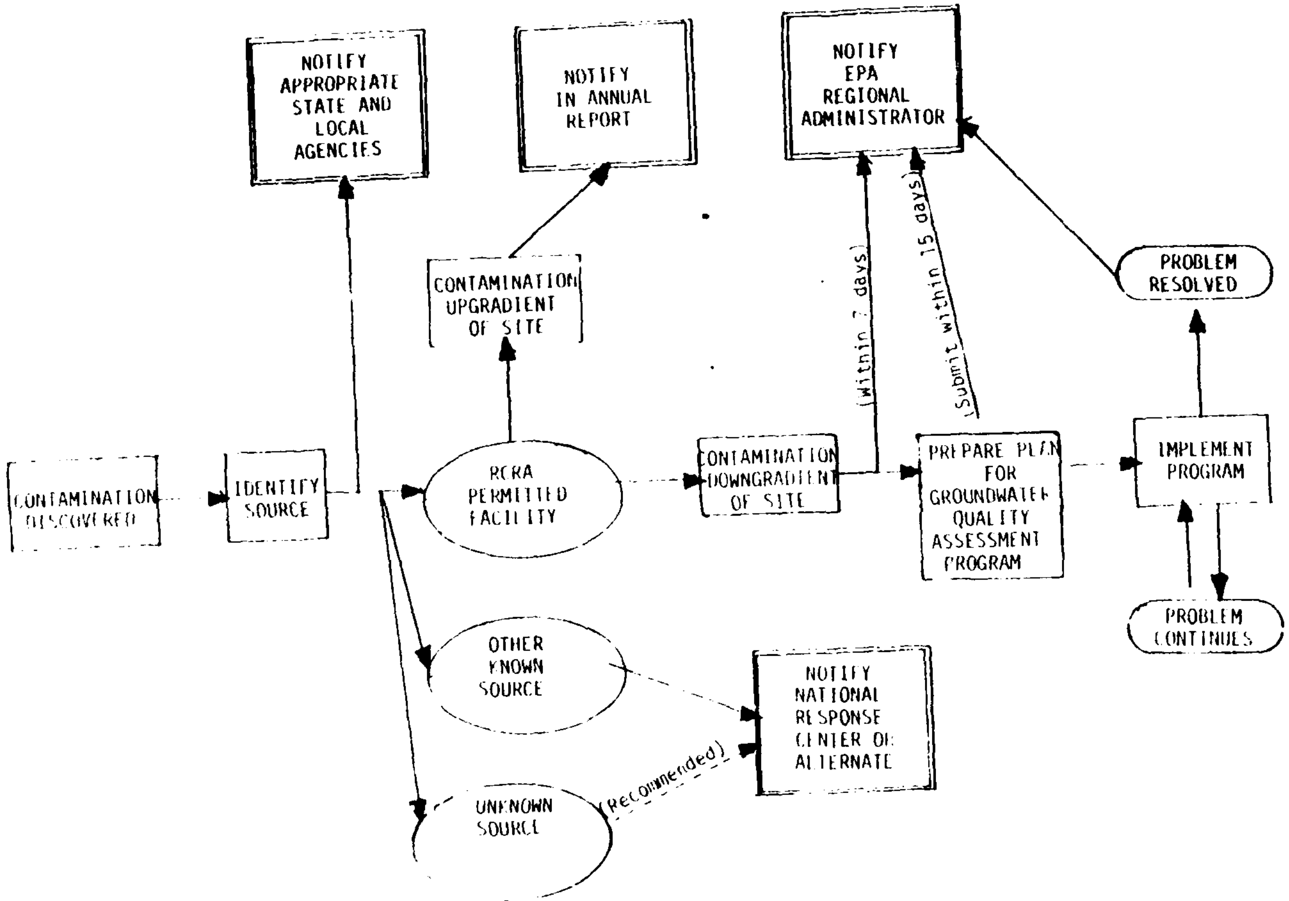

Figure 9. Regulatory Response to Groundwater Contamination

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